Thermodynamics

The science of heat and heat transfers

Two 19th-Century Insights

Heat is a form of energy.

Energy is conserved and can be changed from one form to another.

The First Law of Thermodynamics

In an isolated system, the total amount of energy is conserved.

Alternative statements of the First Law of Thermodynamics

- Energy cannot be created or destroyed, only changed from one form to another.
- When heat flows to or from a system, the system gains or loses an amount of energy equal to the heat transferred.
- You cannot get more energy out of a system than the energy you put in plus the energy of the system.
Types of Energy Sources

- Primary sources
  - energy used in the original form
  - Examples
    - Draft animal: mechanical energy of muscle power used as mechanical energy
    - Gas stove: heat from a flame used as heat

- Secondary sources
  - energy converted to another form before use
  - Examples
    - Internal combustion: heat from fuel converted to mechanical energy
    - Hydroelectric power plant: motion of water converted into electricity

Electrical Power Plants

- Generating electricity
  - Turbine
  - Generator
- Turn the turbine by
  - Steam
  - Water
  - Wind
- Steam-powered plants
  - Heat source
    - combustion
    - nuclear reactor
  - Boiler
  - Condenser
  - Water source
  - Cooling towers
  - Heat loss from steam plants

A typical electric power plant

Energy Efficiency

\[
\text{efficiency} = \frac{\text{energy output}}{\text{energy input}}
\]

- Used when energy is converted from one form to another
Heat Engine

- Obtains work from the flow of heat
- Components:
  - Heat reservoir
  - Heat sink
  - Object on which work is done
- Can all the heat be converted into work?
  - Is 100% efficiency possible?

Efficiency of a heat engine

- When heat is converted into work, the temperature of the heat source falls.
  - Remember the melting ice!
- The object on which work is being done is not isolated from the heat engine.

Efficiency of a heat engine

- For heat to flow from a source to a sink, there must be a temperature difference.
- When heat is transferred from one body to another, the temperatures equalize.
  - The temperature of the heat source falls; that of the heat sink rises.
- When temperatures are equal, no more heat can be transferred.

Efficiency of a heat engine

- If there is no temperature difference, no heat can be converted into work.
  - It is the flow of heat that produces work.
  - No temperature difference → no heat flow.
- If there is a temperature difference, some heat will be used to equalize temperatures.
  - 100% efficiency is impossible.
Efficiency of a heat engine

\[ \text{efficiency} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}} \]

- 100% efficiency is impossible

Nicolas-Léonard-Sadi Carnot

Energy cannot be used without waste

- All real objects contain energy.
- Much of the energy is not useable.
  - Thermal energy is “low-grade energy.”
- Energy tends to dissipate into unusable forms.
  - Temperatures equalize.
  - Energy is “dissipated” as heat.

The Second Law of Thermodynamics

The entropy of an isolated system remains constant or increases.

Alternative statements of the Second Law of Thermodynamics

- In an isolated system, energy always changes from more useful to less useful forms.
- Heat will not flow spontaneously from a cold body to a hot body.
- You cannot construct an engine that does nothing but convert heat to useful work.
- NOT “Every isolated system becomes more disordered with time.”
Consequences of the Second Law

- The arrow of time.
  - Time “moves” from lower-entropy states to higher-entropy states.
- Built-in limitations of the universe
  - heat death of the universe
  - wastage of energy
- The existence of complex, dynamic systems
  - Organized matter requires the Second Law.

Ilya Prigogine, The End of Certainty

The Second Law of Thermodynamics makes life possible.

- Decreases in entropy are possible in open or closed systems.
- Complex, dynamic systems maintain themselves by “dumping entropy into their environment.”
  - Entropy decrease in a computer is paid for by an entropy increase in its power source.
  - Entropy decrease in the biosphere is paid for by an entropy increase in the sun.